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NRL Memorandum Report 1790
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Analog System Configuration for the Performance of Real Time Acceleration and Velocity Analysis of Missile or Aircraft-Type Targets

[Unclassified Title]

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Radar Techniques Branch
Radar Division

July 14, 1967

NAVAL RESEARCH LABORATORY
Washington, D.C.

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ABSTRACT
(Secret)

The overall radar problem must be considered when determining the design of the signal processor in order to achieve optimum radar performance. The choice of signal processor type for a high frequency, over-the-horizon pulse doppler radar is of particular importance because it must perform maximum signal enhancement to detect and observe very small signals buried in noise and simultaneously extract the maximum of target information.

An acceleration and velocity signal processor that combines the features of multisecond coherent integration and spectral compression is capable of providing large signal-to-noise enhancement plus acceleration and velocity data of good resolution for either accelerating targets or constant velocity targets; and it is considered to be quite suitable for this application. A signal processor of this type may be implemented as an analog system by one of three alternate methods that are described, but one is preferred for expressed reasons. Consideration is given to backscatter rejection, memory requirements, and required parameter coverage and hardware.

PROBLEM STATUS

This is an interim report on the problem. Work on other phases of the problem is continuing.

AUTHORIZATION

USAF MIPR (30-602) 64-3412 to the
Naval Research Laboratory,
dated 26 March 1964
NRL Problem 53R02-42

I. INTRODUCTION

The basic purpose of the HF, OTH radar is to detect and observe moving targets at long OTH ranges. Since targets of interest include missiles as well as aircraft a wide extent of velocities and accelerations may be expected, and signal amplitudes may be any value from well below noise level to a high level. The usefulness of the overall radar is determined by its ability to detect the desired signals and by the quality of the data it can provide. Backscatter and interference further complicate the problem. When the overall radar problem is considered it becomes evident that a great deal of emphasis should be placed upon the signal processor capability in order to achieve a significant enhancement in SNR and to provide both acceleration and velocity data with good resolution. It is only through this capability that small signals as well as large ones may be detected for either constant velocity or accelerating targets. Much useful information is contained in the small signal responses. These include such items as long-range aircraft targets, early time missile detections, skin tracks of spent missile stages, and separated missile parts including reentry bodies. The high amplitude enhanced target cross-section signals upon which less sensitive radars depend for detections may be denied to them by vehicle programming or by other means.

II. APPROACH TO THE SIGNAL PROCESSOR PROBLEM

High values of signal-to-noise enhancement and excellent velocity resolution may be realized for aircraft-type targets which are of nearly constant velocity by the use of multisecond coherent integration. The first figure, (Fig. 1) shows a block diagram of a velocity analyzer of this type that has been used successfully for aircraft tracking. Velocity analysis is performed by effectively scanning a single, narrow band doppler filter across the doppler frequency extent. A signal memory records the receiver synchronous detector bipolar output for the multisecond integration interval and is subsequently read out at a far higher rate. The resulting time compression effects a multiplication of all doppler frequencies at the memory output and therefore analysis is performed at multiplied frequencies where the time response of filter bandwidths, for full doppler resolution commensurate with the integration period, is short enough to allow full analysis to be performed in real time. Full coherent integration requires that the integration be performed before detection, but several authors have shown that if a significant SNR is assumed necessary for detection, say 13.5 dB or so, then a part of the integration may be performed after detection with very little loss of SNR as compared to that obtained with full coherent integration. Doppler resolution may then be traded for a further decrease in analysis time. In the case of long integration periods this provides excellent SNR enhancement, and still retains adequate velocity resolution while allowing multiple analysis cycles to be completed within the time interval of the signal storage. It should be mentioned that the postdetection filter has an equivalent doppler bandwidth of approximately the inverse of the signal storage time.

While this velocity analyzer performs well for aircraft-type targets, it loses sensitivity and velocity resolution for signal returns from accelerating targets. This may be seen from Fig. 2. An input signal was first simulated for one which might be received from a constant velocity target, and the output of the velocity analyzer is shown in the top view. The vertical scale shows amplitude, and the horizontal shows equivalent doppler frequency covering the full doppler extent. The input amplitude was adjusted for a full scale output. Next, the input signal was simulated for one that would be received from an accelerating target whose doppler frequency changed during the signal storage interval by 36 c/s. At a carrier frequency of 20 Mc/s this is equivalent to a radial acceleration of 2.7 G. The velocity analyzer output for this case is shown in the lower view. Although the input amplitude remained exactly the same as in the first case, the analyzer output is decreased by about 20 dB and is fairly uniform in amplitude over the full 36 c/s spread of doppler frequency instead of the single doppler frequency response. The analyzer for this result had a predetection filter with an equivalent doppler frequency bandwidth of 0.36 c/s so it is evident that the input signal was actually spread over 100 such bandwidths and the indicated amplitude loss is in agreement with that which would be expected.

It might appear that the acceleration problem could be accommodated by merely widening the predetection bandwidth, but this is not true and the effects of this change may be seen from Fig. 3. This plot has been made for an operating condition of 45 c/s PRF and a storage time of 10 seconds. Full coherent integration would provide a SNR gain of 26.5 dB for constant velocity targets, but here the predetection filter is widened by a 3.75:1 ratio and a loss of a few tenths of a dB from maximum potential SNR gain results from this cause. The ordinate indicates the SNR gain while the abscissa shows acceleration in G's for a carrier frequency of 30 Mc/s. The SNR gain for a velocity analyzer with the 3.75:1 bandwidth ratio drops rapidly with increase of target acceleration. A little improvement in response to signals from accelerating targets may be realized by further widening the predetection filter bandwidth, but it is not until the postdetection filter is removed that acceleration-caused losses are delayed until significantly higher acceleration values are reached. This has the disadvantage of reducing SNR gain at zero acceleration, and still has acceleration-caused losses at the higher values of acceleration. Although Fig. 3 does not show doppler resolution, it should be indicated that acceleration-caused losses are also accompanied by losses of doppler resolution. Thus, bandwidth widening is not a satisfactory solution. However, it is possible by a method of spectral compression to reduce the spread spectrum to that of the target return signal. By this method, high SNR integration gain and full velocity resolution may be obtained for accelerating targets up to and exceeding 20 G as well as for constant velocity targets, as shown by the horizontal line near the top of Fig. 3. In addition, acceleration information is obtained as an added parameter.

Coherent, multisecond integration combined with a spectral compression-type of acceleration processing is considered a good appraoch for the signal processor design.

The velocity vs time characteristics shown on Fig. 4 for several missile types provide an indication of the accelerations that may be expected. At the steepest part of the Polaris curve, one of the steepest on this chart, a velocity change of 4000 ft/sec occurs in 20 seconds which amounts to 200 ft/sec^2 or approximately 6 G. Some other type missiles such as the anti-missile missile (AMM) may have far greater accelerations, but a signal processor should at least provide efficient analysis for the accelerations encountered with the IRBM or ICBM missile types.

Figure 5 shows how a signal from an accelerating target may be spectrally compressed. An input signal simulated for an accelerating target (the same 2.7 G simulated target as shown previously) causes a velocity analyzer output as indicated by the top view. The vertical scale represents output amplitude and the horizontal scale is calibrated in doppler frequency and shows the full doppler extent. Spectral compression is accomplished by matching the change of doppler frequency characteristic by a similarly modulated oscillator as will be shown shortly, but the result of a match produces the analyzer output as shown in the center view. The spectrum is narrowed and the amplitude raised correspondingly. If the spectral compression had been perfect the amplitude would have been increased to a full scale response, but this shows that most of the signal amplitude response has been recovered. The lower view is for the same set of conditions as the center view, but the horizontal scale has been expanded around the target spectrum. The lines shown are not true spectral lines. Each represents a single output from the analyzer whose predetection filter passband may encompass a number of true spectral lines. The spacing of 0.24 c/s is the amount the filter is stepped in frequency in the step-scanning analysis in this example. This figure does provide a coarse indication of the spectral energy distribution.

III. IMPLEMENTATION OF THE SIGNAL PROCESSOR

Spectral compression is accomplished by the method indicated in the block diagram of Fig. 6[1]. This shows an arrangement the same as the velocity analyzer except that the oscillator is frequency modulated by

1. Initial development of the acceleration and velocity analyzer was performed by NRL and funded by ARPA.

both a velocity and an acceleration input. The signal storage is a sampling process where successive returns from a given range are stored in adjacent positions and all for the multisecond signal storage interval are read out in the time interval of a transmitter pulse width, which here is considered to be 240 microseconds. If the signal were received from an accelerating target its doppler frequency would continuously vary during the signal storage interval. When the frequency modulated oscillator is modulated to match the frequency change characteristic of the signal as read from storage (acceleration match), a constant output frequency will result, and when the starting frequency is also matched (velocity match) a full amplitude output signal will be obtained from the analyzer. The predetection filter bandwidth must be at least wide enough to pass the pulse-type signal fed to it, but it may be widened at the expense of velocity resolution if it is desired to shorten total analysis time. As previously stated, some bandwidth widening may be provided before significant loss of SNR results. Predetection bandwidth widening eases the tolerances for acceleration matching and can thus reduce the number of accelerating matching slopes when possible.

The preceding matched condition was for just one acceleration. It was matched at a specific range and for a specific starting velocity. A full, real-time acceleration and velocity signal processor must provide for matching at any acceleration for any velocity and any range, and be capable of matching more than just one target. This may be accomplished by one of several possible approaches, such as: parallel acceleration channels, parallel velocity channels, or parallel range channels. The first of these is illustrated by the block diagram of Fig. 7. In this method all stored signals are read in range sequence and fed to all analyzers in parallel with the analysis predetection filter of all acceleration channels positioned for one specific equivalent doppler frequency by the velocity modulation generator. Each of the parallel acceleration channels provides an acceleration modulation that repeats once for each range bin readout. Adjacent channels are set for consecutive values of acceleration. After all ranges have been read out and the signals examined at one equivalent doppler frequency, the velocity modulation generator steps to the next velocity where again all ranges are analyzed. The magnitude of the frequency step may be as great as a predetection filter bandwidth, although in practice it is made somewhat less to avoid signal losses at the band edges. The acceleration modulation for each channel repeats the same slope for all ranges and all equivalent velocities. After all velocities have been examined for signals the analysis is complete. Even though real time analysis may be maintained if the analysis time is as long as the signal storage time there are applications where it is desirable to provide multiple analyses per storage time interval. This is true for the case where the stored signal is continuously updated and accelerating targets such as missiles are being observed. When the analysis is performed to the maximum doppler resolution, the predetection filter is operated at its narrowest bandwidth of about the inverse of the signal storage time. This not only causes a maximum number of velocity steps in the analysis but also the maximum of acceleration bins since acceleration matching also becomes more critical. Parallel operation of one of the parameters, in this case acceleration, is essential in order to maintain real time analysis. More rapid analysis is obtained by relaxing the velocity resolution requirement. Notice that a separate acceleration and velocity modulated oscillator is required for each channel. This causes a problem of matching all to the same frequencies and providing adequate stability.

The second method of analysis may be accomplished by providing parallel velocity channels and performing range and acceleration observations in series. This block diagram is shown in Fig. 8. The acceleration modulation is set to the first value while the stored signals from all range bins are fed in sequence to all velocity bins operated in parallel. The acceleration modulation is advanced to the next value as the signals of all range bins are again fed in sequence to the parallel velocity channels. This operation continues until all accelerations have been covered and the analysis is complete. In this method of analysis it would be possible to use one single acceleration modulated oscillator to supply all parallel velocity channels, but there is a problem of doppler foldover at the PRF/2 value of doppler frequency that requires special circuits to solve. Here, each analyzer channel is shown to have its own modulated oscillator in place of the special circuits. Although there is no great reduction in circuits in this method there is a convenient way to stabilize all frequencies to a common reference.

The third method of analysis places the range bins in parallel. This requires parallel readout of range information from the signal memory. While this mode of readout is not convenient with the currently used disk or drum memories it is easily accomplished with other types. Figure 9 shows the parallel range type of analyzer. In this method the signal memory is read out simultaneously for all range bins and fed to all range bin analyzers in parallel. Analysis is begun by setting the velocity and acceleration modulated oscillator for the first velocity and the first acceleration bin. The velocity modulation is stepped once after each range readout and the acceleration modulation remains the same until all range bins have been read out at all possible velocity settings for the first acceleration modulation. Then the process is repeated for the second acceleration modulation at all velocities, etc., until full analysis is accomplished. There are several advantages to this method. Only one velocity and acceleration modulated oscillator is needed for all parallel channels. This reduces the amount of required hardware and concentrates the frequency stability problem to a single oscillator. Another advantage is obtained by supplying fewer parallel channels. The number of velocity and acceleration bins is controlled by the number of sequential operations and may be easily tailored to the selected predetection bandwidths.

On the basis of the quantity of electronic hardware required by each of these methods and the consideration of the sweep frequency generation and stabilities necessary, the parallel range type of analyzer is preferred. The development of this system has been initiated.

IV. SIGNAL MEMORIES

The signal memory is an integral part of the acceleration and velocity signal analyzer. Its purpose is to provide signal storage for a multisecond interval for all operating PRF's of the radar system, and perform readout at a sufficiently high rate that will provide great enough frequency multiplication that full signal analysis may be performed within the time of a signal storage interval. Typical values of PRF may be as high as 180 c/s and storage times as long as 10 seconds. Signal dynamic range should be as great as possible, say 140 dB if attainable. Until recently the only available signal memories on this OTH radar program at NRL have been magnetic drum or magnetic disk analog memories. While these provide storage at a low cost per element and high readout rates they have serious limitations primarily in dynamic range capability but also in the mechanical drive and associated complexities. Dynamic range has been limited to about 30 dB. Recent work has been devoted toward signal processors with improved memory systems. One of these methods for improvement is by the use of a new, capacitor-type analog signal memory which is now in the process of development[1]. This memory offers the promise of a linear dynamic range in the order of 100 dB or more, and is increased to more than 120 dB when the processing gain that follows is taken into account. The signal memory is made up of separate 900-element memory planes for each range bin to accommodate an input signal with a 90 c/s repetition rate and a ten-second signal storage. Provision is made for other combinations of PRF and storage times within the total element capacity. All range bins are normally read out in parallel and at a 7.5 Mc/s readout rate, but it is possible to arrange for a sequential range readout. The implementation of the memory is being done with microelectronic circuits and while this first unit has stressed maximum performance rather than small size the ten-plane memory including logic circuits and the radar clock and synchronizing circuits are all contained in a single rack. The memory offers great flexibility such as the independence of write and readout rates and also avoids the problems of mechanical drive systems needed by drum or disk memories. The results of the development are encouraging and it now appears that design goals will be met.

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1. This development is currently being funded by USAF, Rome Air Development Center.

V. ADDITIONAL CONSIDERATIONS

A. Backscatter

Backscatter presents one of the problems of signal processing. When the system linear dynamic range is severely restricted as it is with some signal memory types, it is considered necessary to filter the backscatter components from the signal ahead of the memory. So far the most successful method has been by the use of quartz crystal comb rejection filters, but these are constructed for specific repetition rates. While digital techniques offer a possible alternative, their full capabilities remain to be established. If a signal memory can be provided to handle the full required dynamic range, the separation of backscatter components may be accomplished by a high pass filter following the signal memory. This memory is independent of PRF and would provide the possibility of adjusting the width of the rejection band to conform to existing conditions.

B. Contiguous Filters

A set of parallel contiguous filters is provided between the signal storage and the acceleration-velocity analyzer chassis. These filters divide the multiplied doppler frequency band into a number (possibly ten) of equal bandwidth sections. An amplitude limiter is provided after each of the filters to limit signals to a selected level, and a second filter follows the limiting stage to remove harmonics that might be introduced. The limiting level is normally adjusted so that the random noise is just below limiting, and therefore signals below noise level are not degraded by limiting. In each channel the SNR is improved by reason of the bandwidth narrowing. Signals from all filter channels are recombined at the output. The purpose of this set of filters is to remove large interfering signals so that they do not mask desired signals that are possibly of low level, as is necessary prior to acceleration processing. Frequently signals from accelerating targets will occupy more than one filter bandwidth. If the interference is contained in other filter passbands or in only a part of the passbands occupied by the desired signal, the desired signal may still be observed. This set of filters may also be used to perform backscatter rejection if previous circuits possess sufficient dynamic range.

C. Velocity Ambiguity

In a pulse doppler radar, velocity ambiguity occurs whenever doppler frequencies exceed one-half the PRF, and range ambiguity occurs when the two-way propagation time to the target exceeds 1/PRF. Both high velocities and long ranges are of interest in an OTH radar; thus a compromise value of PRF is normally chosen. One method of resolving velocity ambiguities is made possible by the transmission of long pulse lengths. The resulting frequency spectrum will contain few lines of significant amplitude so that the center of spectral energy may be determined. This method may be extended to provide accurate velocity resolution with the addition of separate filters about each of the spectral lines where each filter bandwidth is equal to the PRF. The required number of adjac..nt filters is determined by total doppler coverage. Suitable handling of these outputs will preclude any possible doppler foldover and subsequent analysis may be performed to high resolution without ambiguity. If wide pulse transmission is combined with pulse compression it is possible to also obtain adequate range resolution. An increase in circuit complexity is required and a block diagram of this method is shown by Fig. 10.

VI. CONCLUSIONS

It is concluded that a real time signal processor suitable for a HF, OTH radar should provide multisecond coherent signal integration in combination with an acceleration and velocity analyzer to provide good SNR gains and acceleration and velocity resolution for both accelerating and constant velocity targets. The acceleration parameter provided in the process is a useful aid to the detection and classification of targets. A preferred method of implementation is a system consisting of parallel range channels and serial sequencing of acceleration and velocity matching because it minimizes the amount of required electronic hardware and also minimizes the problem of frequency sweep stabilization and alignment.

A capacitor-type analog signal memory now in the process of development is well suited for this application and promises a significant improvement in the signal processor capability. Other system problems have been given careful consideration and practical solutions are available.

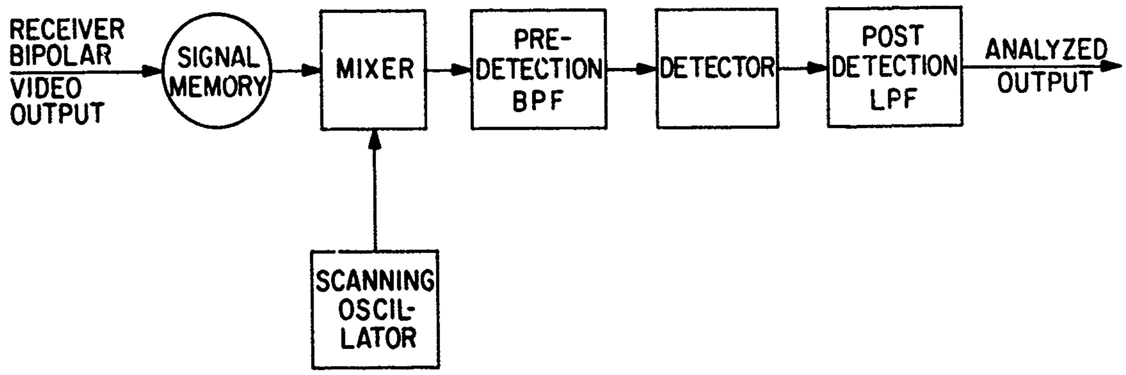


Fig. 1 - Velocity Analyzer

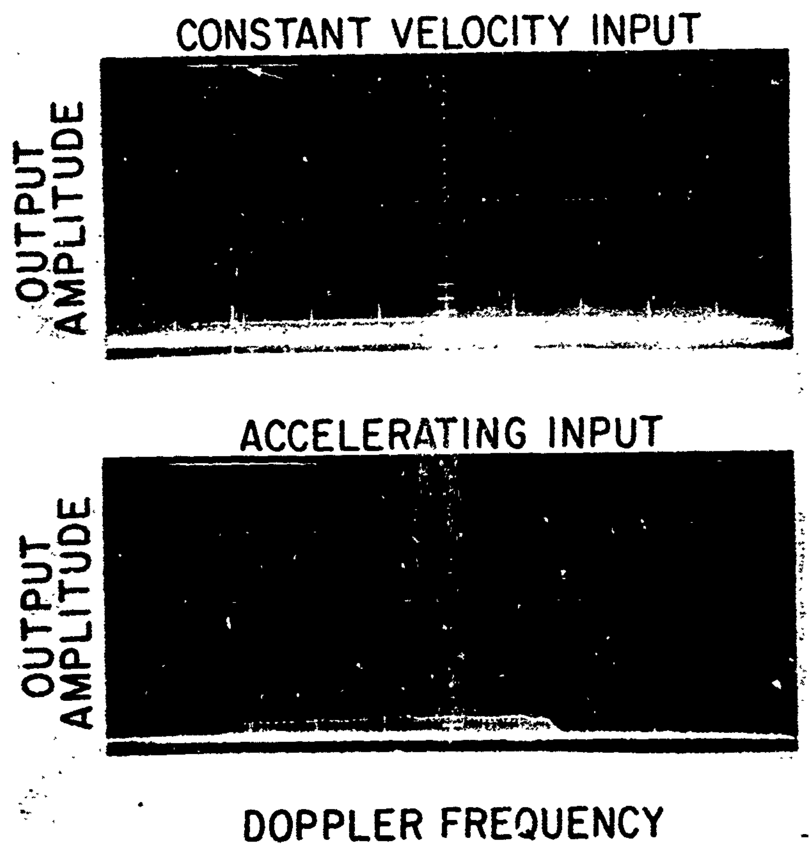


Fig. 2 - Velocity Analyzer Output for Simulated Input Signals. Top View: Simulated Constant Velocity Target. Bottom View: Simulated Accelerating Target.

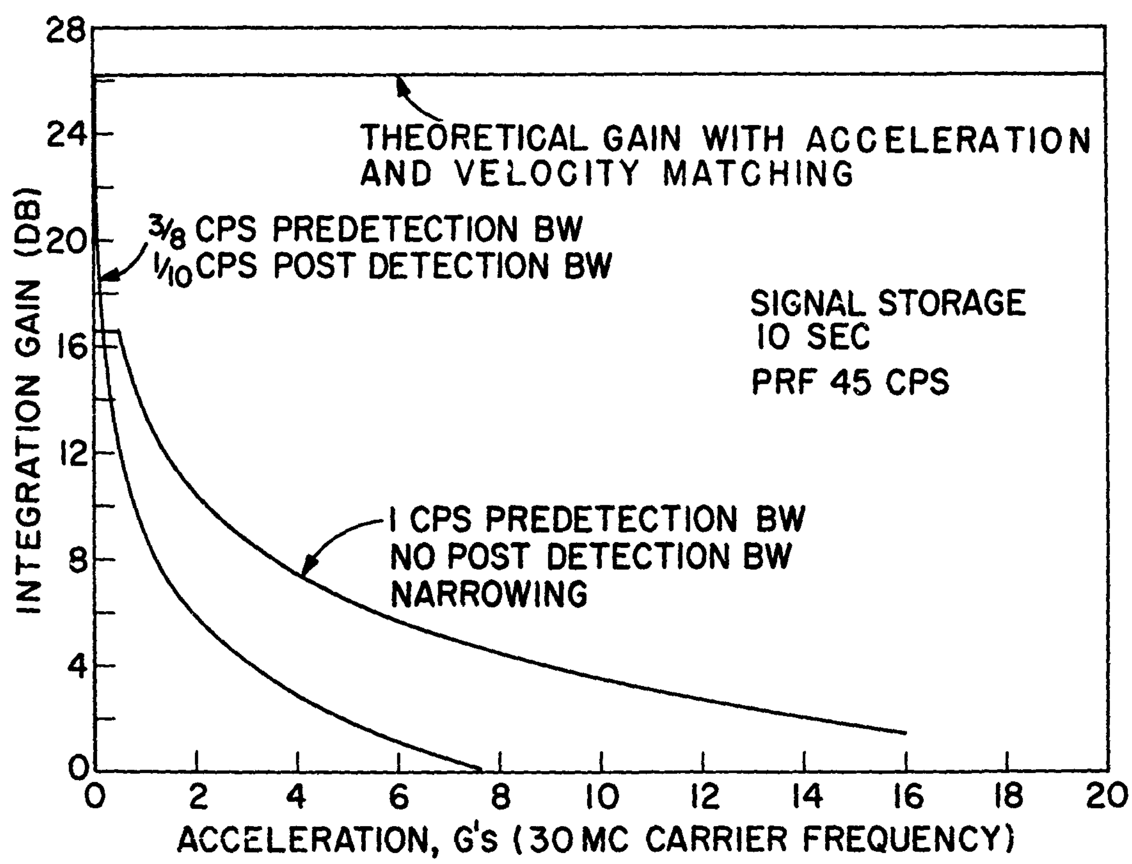


Fig. 3 - SNR Gain vs Target Radial Acceleration

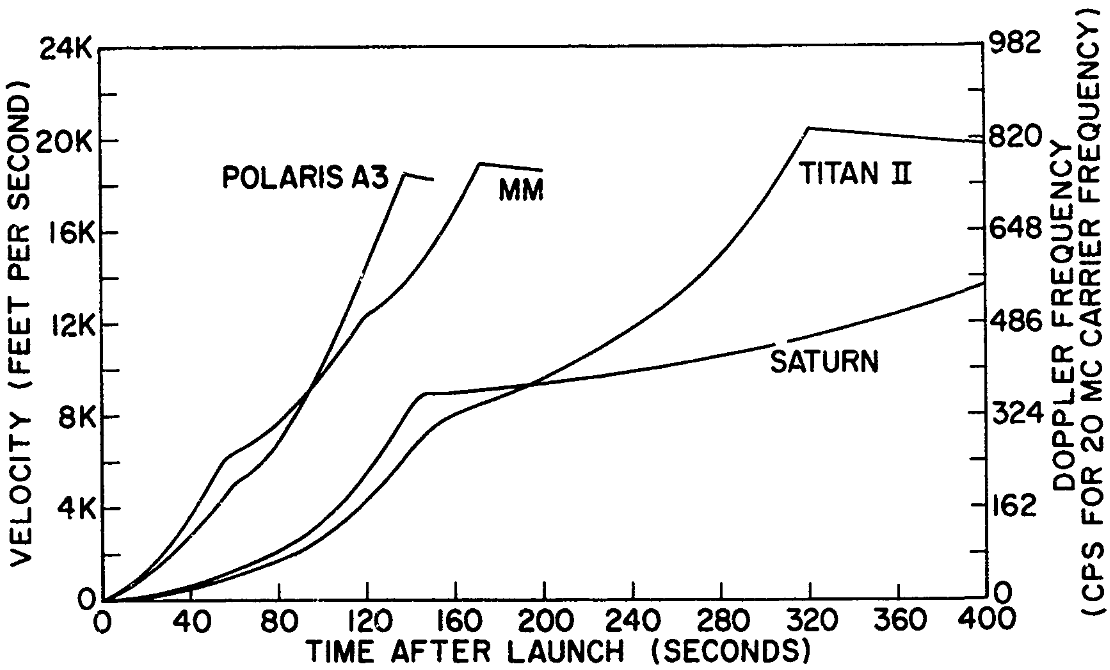


Fig. 4 - Velocity vs Time After Launch Characteristics for Several Missile Types

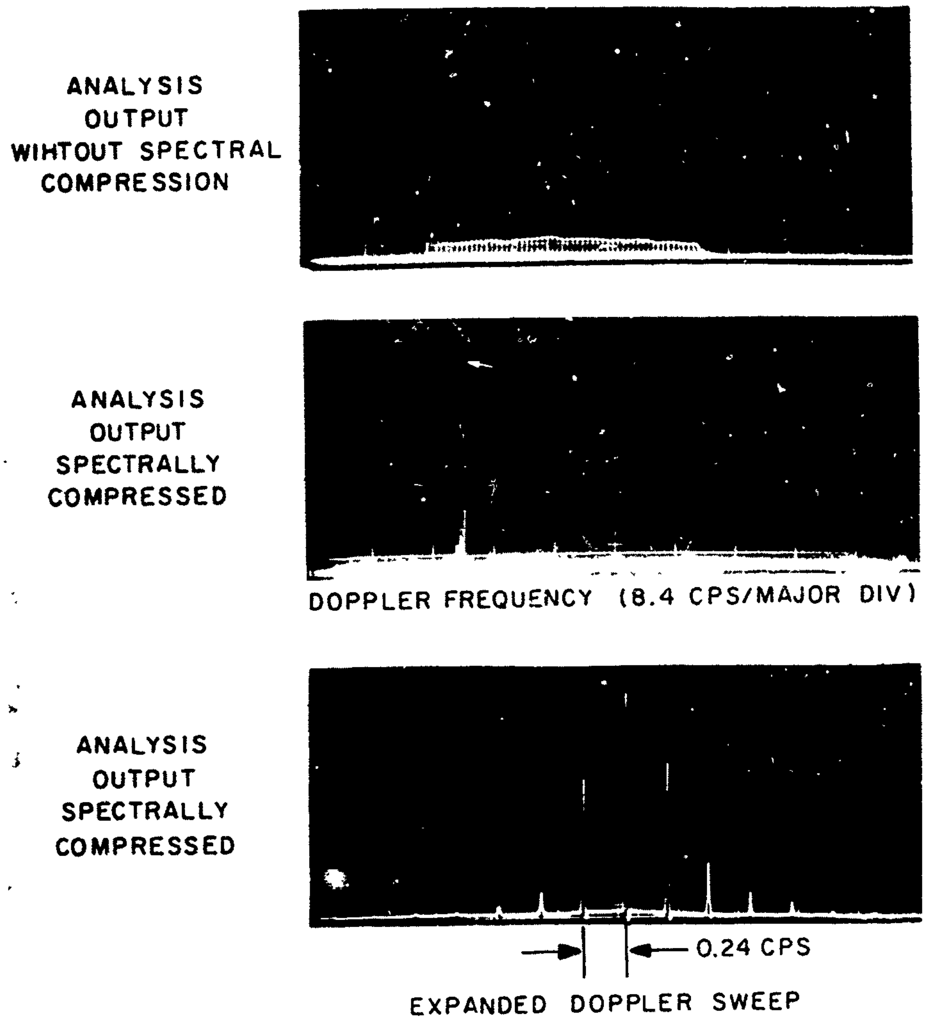


Fig. 5 - Analyzer Output for Simulated Input 36 c/s Acceleration Spread Doppler (100 Bandwidths). Top View: Analysis Output without Spectral Compression. Center View: Analysis Output Spectrally Compressed. Bottom View: Analysis Output Spectrally Compressed with Doppler Sweep Expanded.

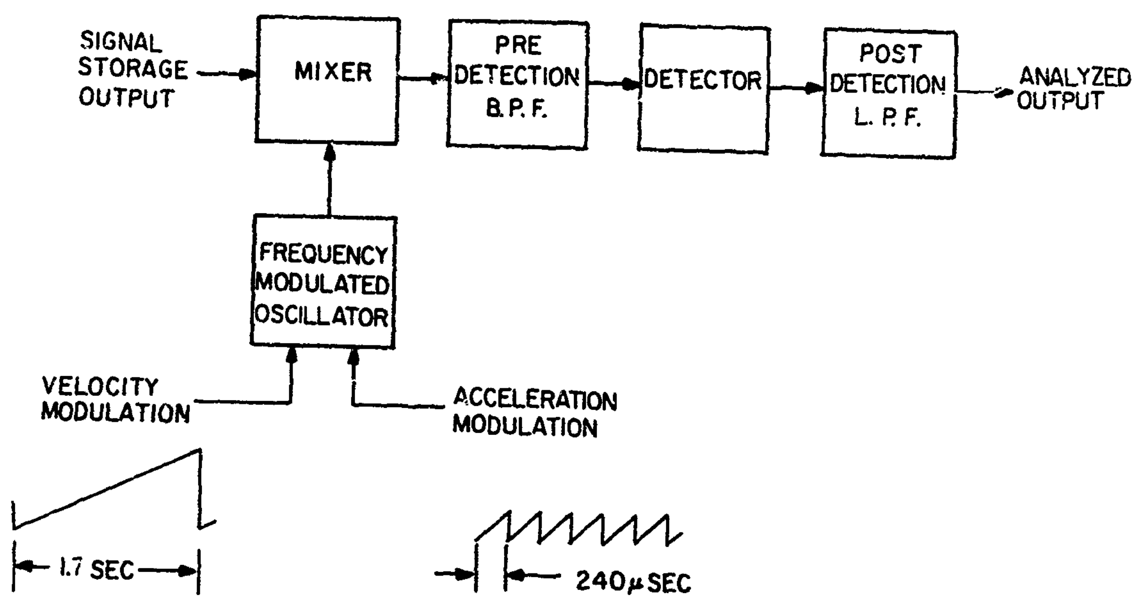


Fig. 6 - Acceleration Gate Analysis Channel

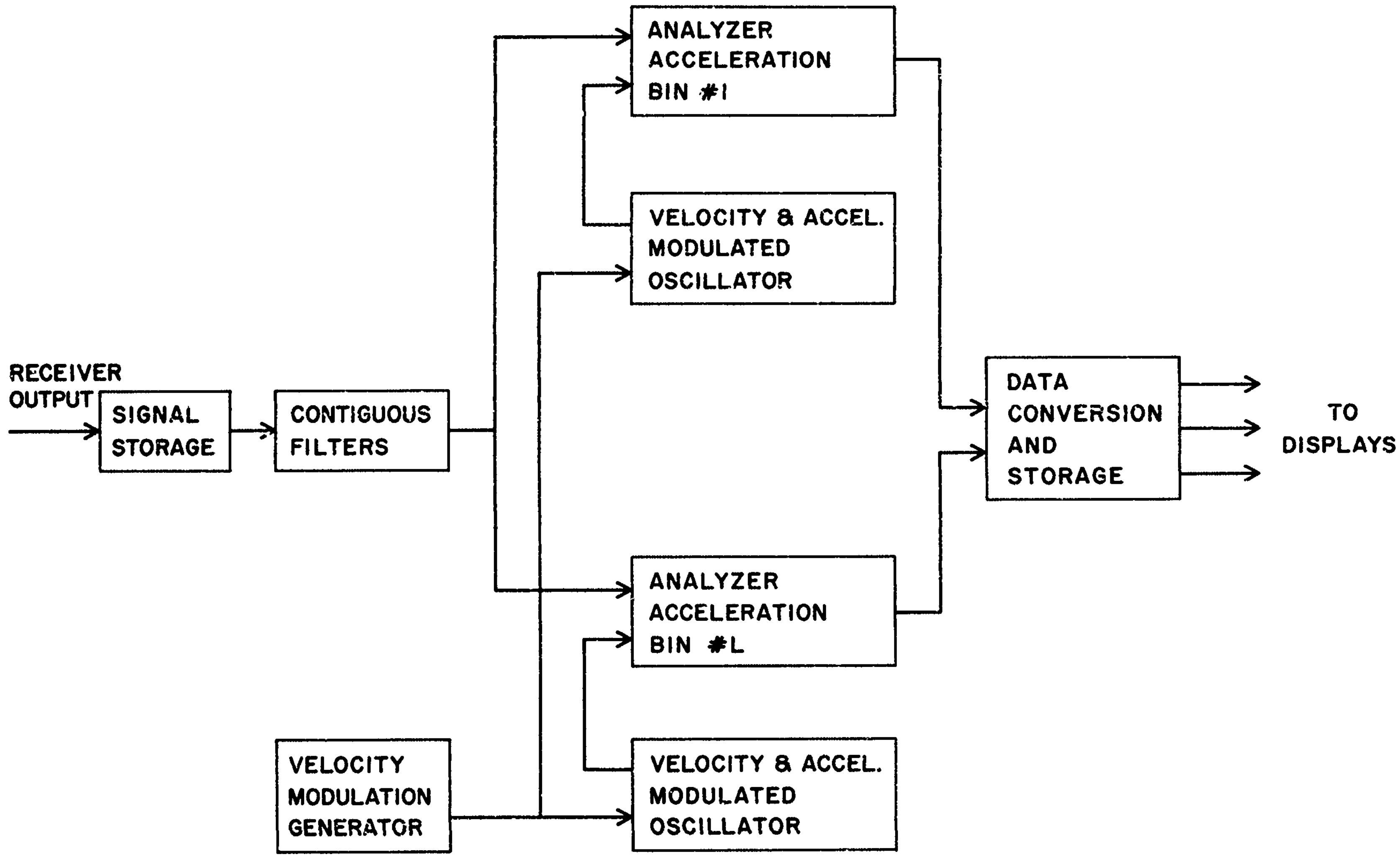


Fig. 7 - Parallel Acceleration Type Acceleration, Velocity, and Range Analyzer

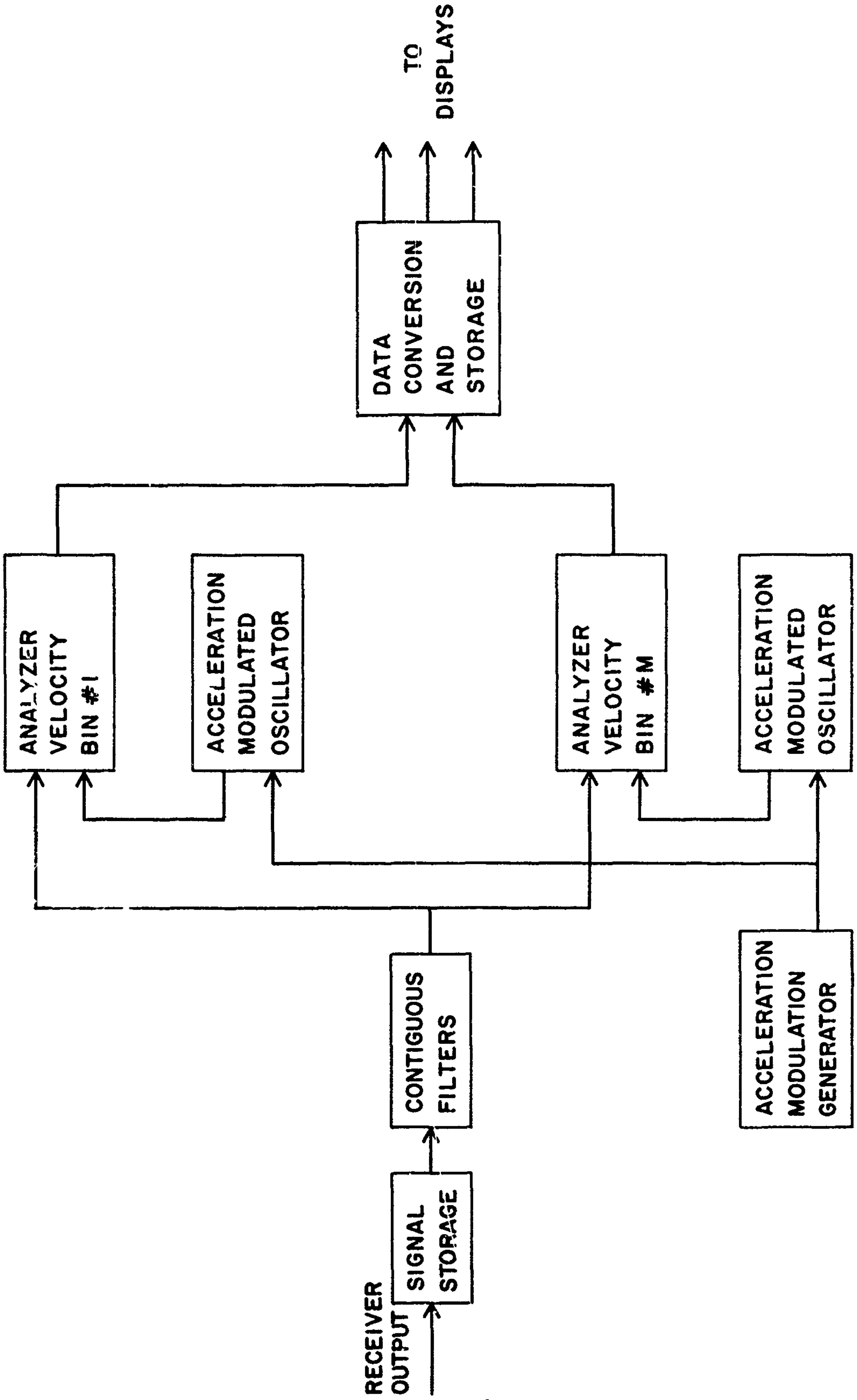


Fig. 8 - Parallel Velocity Type Acceleration, Velocity, and Range Analyzer

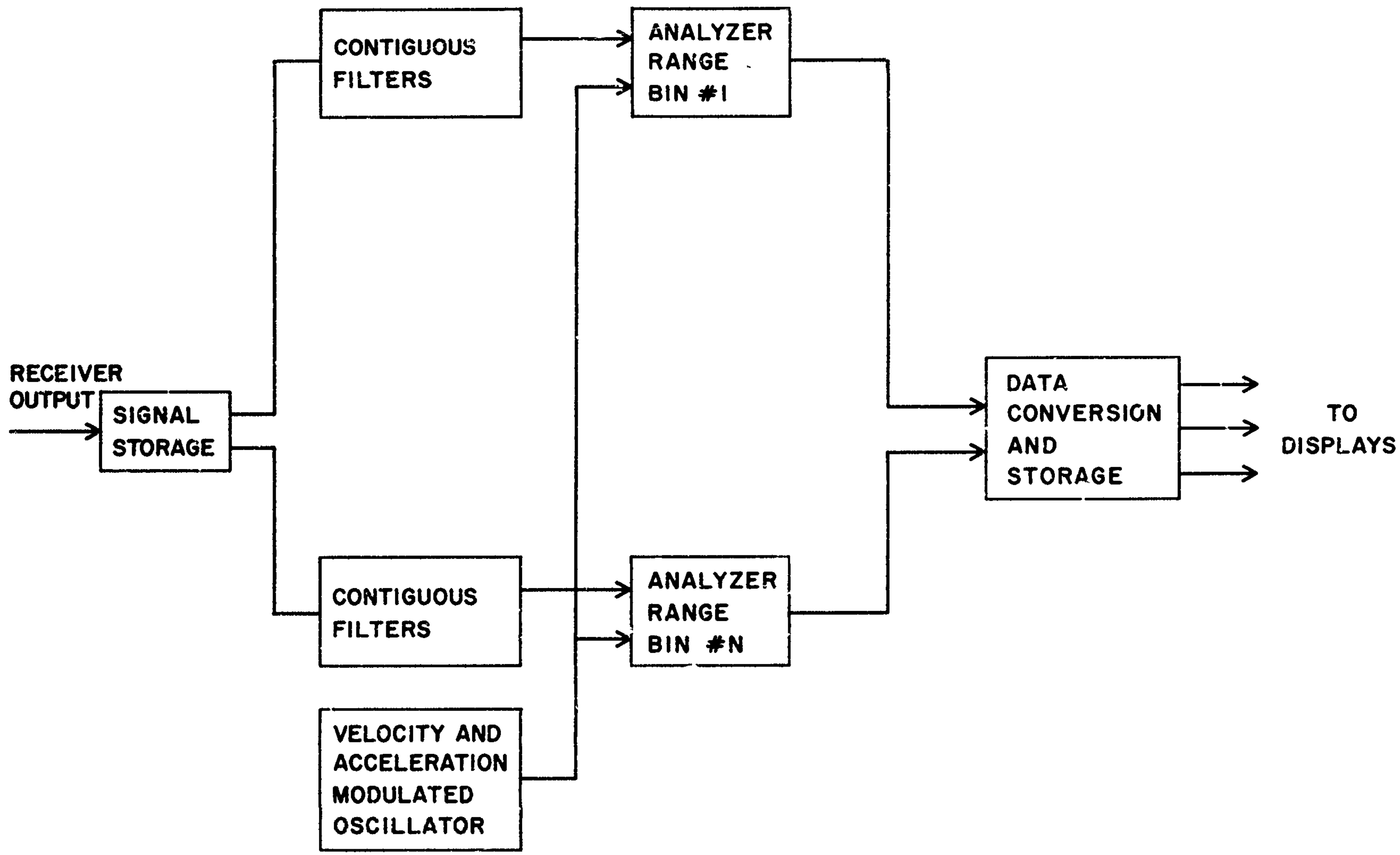


Fig. 9 - Parallel Range Type Acceleration, Velocity, and Range Analyzer

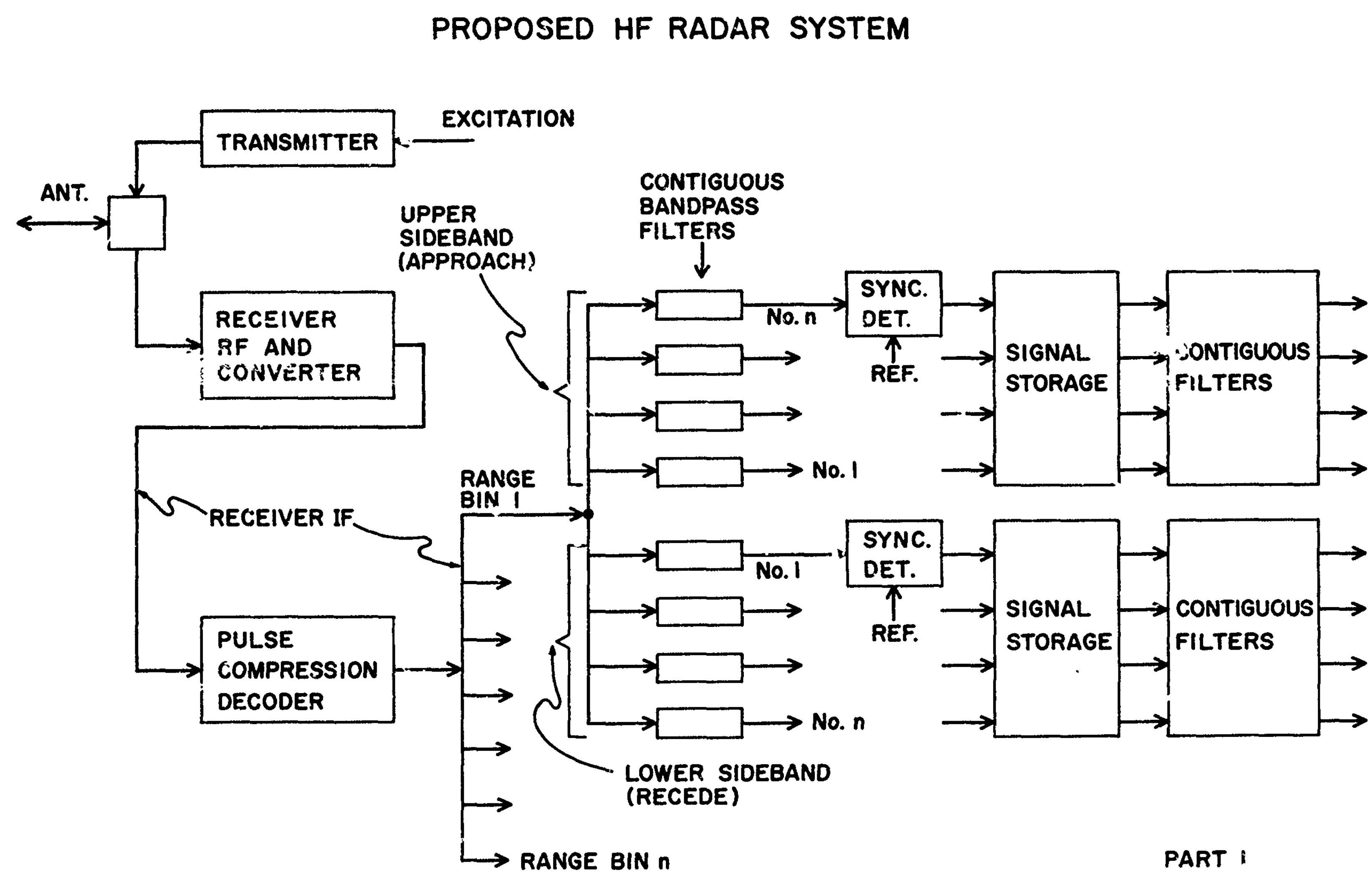
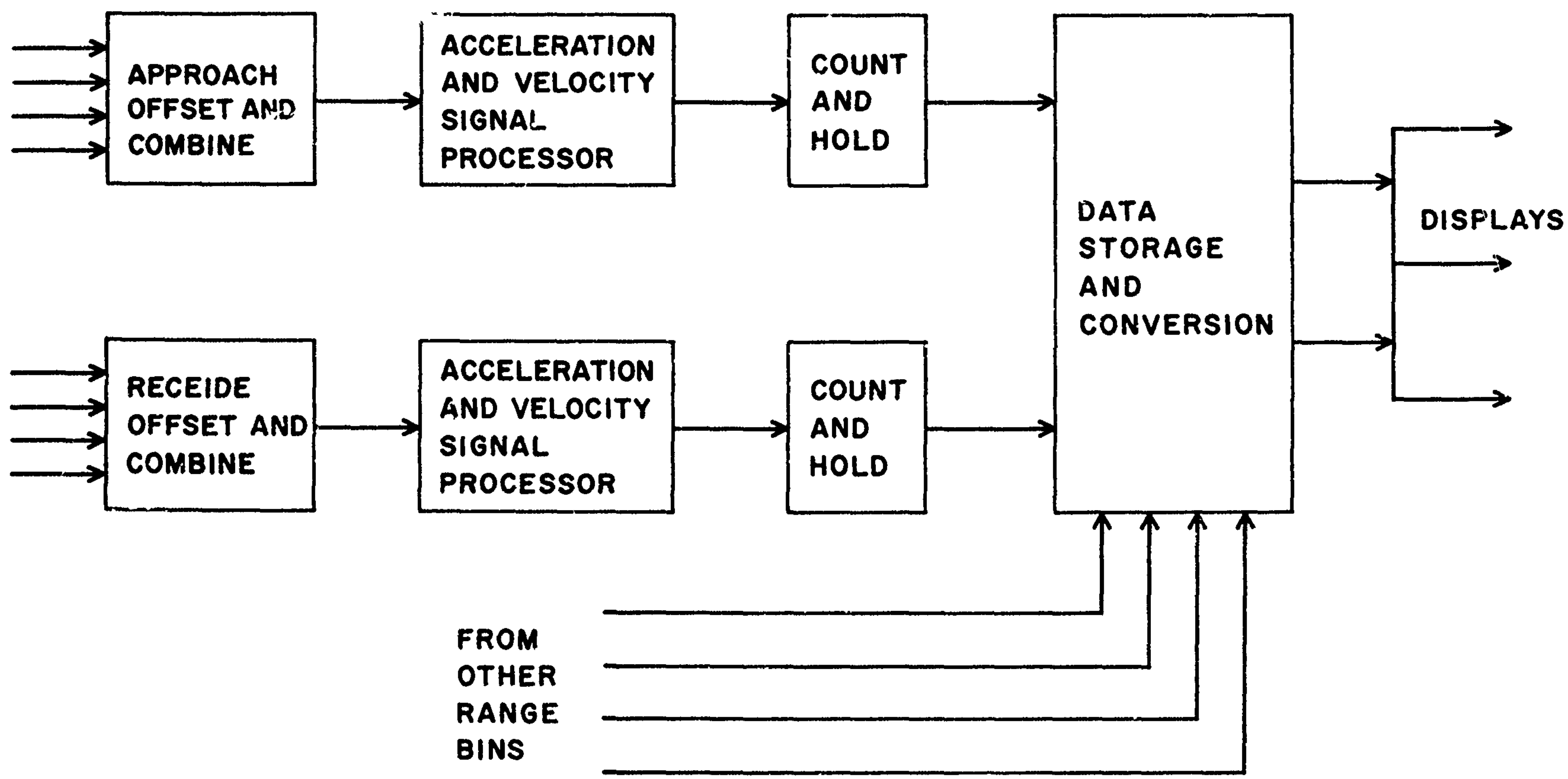


Fig. 10A - Implementation of Full Radar System Providing Acceleration, Velocity, and Range Analysis by a Parallel Range Type Analyzer Including Means to Eliminate Range, Velocity, and Acceleration Ambiguities

PROPOSED HF RADAR SYSTEM



PART 2

Fig. 10B - Implementation of Full Radar System Providing Acceleration, Velocity, and Range Analysis by a Parallel Range Type Analyzer Including Means to Eliminate Range, Velocity, and Acceleration Ambiguities

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13 ABSTRACT

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The overall radar problem must be considered when determining the design of the signal processor in order to achieve optimum radar performance. The choice of signal processor type for a high frequency, over-the-horizon pulse doppler radar is one of particular importance because it must perform maximum signal enhancement to detect and observe very small signals buried in noise and simultaneously extract the maximum of target information.

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MEMORANDUM

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Memo: 1251, 1287, 1316, 1422, [redacted], 1500, 1527, 1537, 1540, 1567, 1637, 1647, 1727, 1758, 1787, 1789, 1790, 1811, 1817, 1823, 1885, 1939, 1981, 2135, 2624, 2701, 2645, 2721, 2722, 2723, 2766. Add 2265, 2715.

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